REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-01-

0606

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPOR
		15 NOV 98 - 14 OCT 00

4. TITLE AND SUBTITLE
Real-Time Predictive Flutter Analysis and Continuous Parameter Identification of Accelerating Aircraft

5. FUNDING NUMBERS
F49620-99-1-0037

6. AUTHOR(S)
Charbel Farhat

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Department of Aerospace Engineering Sciences
Center for Space Structures and Controls
University of Colorado at Boulder
Boulder, CO 80309-0429

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NM
801 N. Randolph Street Room 732
Arlington, VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-99-1-0037

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The present proposal requests high-end computer equipment to interface with and upgrade an existing parallel computing facility dedicated to the support of a Test & Evaluation research project currently funded by AFOSR, and conducted by three faculty, three graduate students, and two post-doctoral researchers at the Center for Aerospace Structures at the University of Colorado in Boulder, This research project pertains to the development of a real-time predictive flutter analysis capability, and the design of a continuous parameter identification method for extracting and monitoring the aeroelastie frequency and damping values of an accelerating fighter- An upgrade in processing power is requested to enable the continuation of this active and AFOSR funded research effort, as well as to support new Test & Evaluation research tasks that are currently being discussed with the Flight Test Center at the Edwards Air Force Base. The requested upgrade will transform the existing equipment into a high-end distributed computing platform that will remain dedicated to AFOSR Test & Evaluation research efforts. This new computational platform will accelerate the impact of our AFOSR funded research on the development of new aircraft such as the F22, the TSP, and the next generation UAVs. It will also enable the contribution of our research efforts to increasing flight safety during aggressive maneuvering, and reducing the number of flight test hours required for expanding the flutter envelope of current and next generation fighters.

14. SUBJECT TERMS

20011212 170

15. NUMBER OF PAGES
4

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
GRANT F49620-99-1-0037

Final Report - January 2001

CHARBEL FARHAT

Department of Aerospace Engineering Sciences
Center for Space Structures and Controls
University of Colorado at Boulder
Boulder, CO 80309-0429

SUMMARY

This is a four-part final report on the research supported by the Air Force Office of Scientific Research Center under Grant F49620-99-1-0037, entitled **Real Time Predictive Flutter Analysis and Continuous Parameter Identification of Accelerating Aircraft.**

1. Motivations and research objectives

Flutter clearance, which is part of any new aircraft or fighter weapon system development, is a lengthy and tedious process from both computational and flight testing viewpoints. An automated approach to flutter clerance that increases flight safety and reduces flight hours requires as a stepping stone the development of a real time flutter prediction capability. Such a fast analysis tool can be designed if the coupled fluid/structure aeroelastic system is represented by a simplified mathematical model that can be quickly adapted to changes in flight atmospheric conditions, aircraft mass distribution (weapon systems), fuel loading, and Mach number, and if the current parallel processing technology is exploited.

Furthermore, flight testing is always required to establish the flutter envelope of an aircraft. The traditional method for determining such an envelop uses test data extracted from the vibration response of the aircraft at fixed flight conditions. The aircraft is first trimmed to a specific flight condition (Mach number and dynamic pressure), then its aeroelastic response is deliberately excited by applying an input to a flight control surface. The frequency and damping of the excited aeroelastic response are typically extracted from

the vibration data. By repeating this test at many flight conditions, the flutter envelope can be determined. Such a traditional approach requires that the aeroelastic response be measured at many different flight conditions. This often requires a large number of flight test hours, a process which not only costs money but also exposes test pilots to proportionately increased risk. However, this test procedure can be expedited if data collected from continuously varying flight conditions can be used to extract the needed flutter damping and frequency values from an accelerating flight profile. In that case, it may be possible to greatly reduce the number of flight hours required for establishing the flutter envelope.

The Air Force Flight Test Center at the Edwards Air Force Base (AFB) has expressed great interest in the above two problems, and therefore we have proposed to conduct a three-year research effort in real time flutter analysis, and the continuous parameter identification of an accelerating aircraft. More specifically, we have proposed to develop a simplified flutter analysis method that can be run real time to provide predictive frequency and damping values for maneuvers as flown. The enabling technology of such a real time flutter analysis capability is a formulation of the aeroelastic problem that allows, among other things, partial pre-solutions and the usage of parallel processing. We have reported on this research activity during the first year of support.

We have also proposed to develop a parameter identification technique that can be used to extract frequency and damping values of an aircraft that is continuously accelerating. This technique should reduce both the cost and risk involved in determining the flutter envelopes of fighters. Here, we report on this effort which has been conducted during the last two years in collaboration with the researchers and engineers of the Air Force Flight Test Center at the Edwards AFB.

2. Major accomplishments during the last two years of support

We have determined that two fundamental issues must be addressed before a method for the continuous parametric identification of an accelerating aircraft can be developed. The first issue deals with how the aeroelastic properties of an aircraft can be affected by a constant acceleration in a level flight or during maneuvering. In particular, is it possible to relate in a simple way the aeroelastic parameters measured in an accelerated flight to those measured in stabilized flight conditions? The second issue is related to the fact that most if not all identification methods used in practice implicitly assume that the given aeroelastic system is linear and non-varying in time. Whether these methods can still be used to analyze accelerated flight data, or whether new methods are required for this purpose was an open question.

During the last two years of funding, we have addressed important aspects of the above two issues by performing appropriate analytical studies and CFD based numerical simulations. More specifically, we have first considered a typical NACA 0012 wing section, and investigated the effects of horizontal and vertical accelerations on the aeroelastic response of this system. We have shown analytically that accelerating the wing section introduces additional inertia forces and modifies the torsional stiffness of the aeroelastic

system by a negligible quantity. Next, we have developed a procedure for extracting the frequencies and damping coefficients of an aeroelastic system from time history data of an accelerated flight profile. This procedure is based on a modification of the ERA algorithm, and its interaction with a windowing concept where the Mach number is assumed to be constant in each window. In order to validate this new procedure, we have upgraded our computational aeroelasticity capability to handle accelerated flight, which was by itself an interesting and rewarding research. We have simulated both cases of stabilized flight conditions and accelerated flight. We have compared the generated results and formulated conclusions regarding the theoretical and practical feasibilities of extracting the flutter envelope of an aircraft from an accelerated flight data. These conclusions essentially highlighted the significant potential of this new concept of flight testing. Motivated by our success for the NACA0012 airfoil, we have repeated our simulations of the continuous parameter identification of an accelerating aeroelastic system for a typical F-16 wing section. We have designed this wing section from geometrical and structural data obtained from the Edwards Air Force Base. We have simulated the continuous parameter identification for the F-16 Block 40 typical wing section in accelerated flights with up to 0.05 Mach per second and for flight regimes extending from subsonic to supersonic. We have shown that the aeroelastic parameters identified in accelerated level flight at a given altitude are almost identical to those obtained in stabilized flight conditions, which justifies the proposed new concept of flight testing. However, we could not match perfectly the results of the numerical simulations using the typical wing section with those of the actual test of the F-16 Block 40, particularly for damping. This was because the available test data is for a loaded wing, whereas our typical wing model was derived from a clean wing model, and because the typical wing section approach is valid only for uniform, straight and high aspect ratio wings. All these developments and finding are described in the attached paper "Expanding a Flutter Envelope Using Accelerated Flight Data: Application to an F-16 Fighter Configuration".

Next, we have designed a three-dimensional F-16 Block 40 aeroelastic model using two incomplete finite element structural models acquired from Lockheed-Martin: (1) a static model which does not contain the mass distribution, and (2) a linear "fish-stick" dynamic model which contains the needed mass information but which is not adequate for stress analysis. Using this model, we have obtained numerical results for the F-16 Block 40 that agreed amazingly well the flight test data. This latest development is described in details in the attached paper "'Application of a Three-Field Nonlinear Fluid-Structure Formulation to the Prediction of the Aeroelastic Parameters of an F-16 Fighter".

3. Impact on the state-of-the-art of flight testing

Motivated by the results we have generated under this Grant, the Air Force Test Pilot School performed on May 15-16, 2000, two suites of accelerated flight tests designed by the Principal Investigator and his collaborators at Edwards. The first series of tests was for a clean (no stores) F-16 configuration, and the second for an F-16 configuration known to cause Limit Cycle Oscillations (LCO). In both cases, the flight test team was

able to accomplish ; set objectives using 2.5 times le ;orties than when using the classical stabilized flight testing approach, which demonstrates the potential impact of our accomplishments on the flight testing technology.

4. Publications that have resulted from the last two years of support

1. C. Farhat, P. Geuzaine and G. Brown, "Application of a Three-Field Nonlinear Fluid-Structure Formulation to the Prediction of the Aeroelastic Parameters of an F-16 Fighter," *Computers and Fluids, (submitted for publication)*
2. C. Degand and C. Farhat, "A Three-Dimensional Torsional Spring Analogy Method for Unstructured Dynamic Meshes," *Computers and Structures, (submitted for publication)*
3. C. Farhat, K. Pierson and C. Degand, "Multidisciplinary Simulation of the Maneuvering of an Aircraft," *Engineering with Computers, (in press)*
4. M. Lesoinne and C. Farhat, "A CFD Based Method for Solving Aeroelastic Eigenproblems in the Subsonic, Transonic, and Supersonic Regimes," *AIAA Journal of Aircraft, (in press)*
5. M. Lesoinne, M. Sarkis, U. Hetmaniuk and C. Farhat, "A Linearized Method For the Frequency Analysis of Three-Dimensional Fluid/Structure Interaction Problems in all Flow Regimes," *Computer Methods in Applied Mechanics and Engineering, (in press)*
6. C. Felippa, K. C. Park and C. Farhat, "Partitioned Analysis of Coupled Mechanical Systems," *Computer Methods in Applied Mechanics and Engineering, (in press)*
7. S. Piperno and C. Farhat, "Design of Efficient Partitioned Procedures for the Transient Solution of Aeroelastic Problems," *La Revue Européenne des Eléments Finis*, Vol. 9, No. 6/7, pp. 655-680 (2000)
8. C. Farhat and M. Lesoinne, "Two Efficient Staggered Procedures for the Serial and Parallel Solution of Three-Dimensional Nonlinear Transient Aeroelastic Problems," *Computer Methods in Applied Mechanics and Engineering*, Vol. 182, pp. 499-516 (2000)
9. C. Farhat, C. Harris and D. Rixen, "Expanding a Flutter Envelope Using Accelerated Flight Data: Application to an F-16 Fighter Configuration," *AIAA Paper 2000-1702, 41st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference,* Atlanta, GA, April 3-6 (2000)
10. D. Rixen and C. Farhat, "A Computational Methodology for the Simulation of Flow Problems Past Accelerating Rigid and Flexible Obstacles," (abstract), *Fifth U.S. National Congress on Computational Mechanics,* Boulder, Colorado, August 4-6 (1999)
11. D. Rixen, C. Farhat and L. D. Peterson, "Simulation of the Continuous Parametric Identification of an Accelerating Aeroelastic System," *AIAA Paper 99-0797, 37th Aerospace Sciences Meeting and Exhibit,* Reno, Nevada, January 11-14 (1999)